# Search for Higgs, Leptoquarks, and Exotics at Tevatron

Electroweak Interactions and Unified Theories

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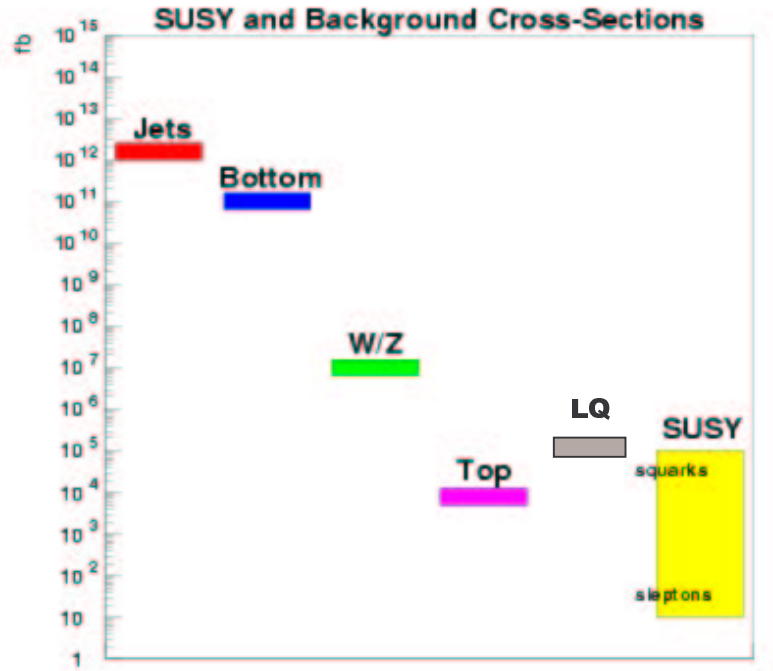
**On behalf of the CDF and D∅ Collaborations**

Outline:

- Introduction
- Report results on Run 2 searches from CDF and DØ
  - Higgs
  - GMSB
  - Leptoquarks
  - Excited Electron
- Summary

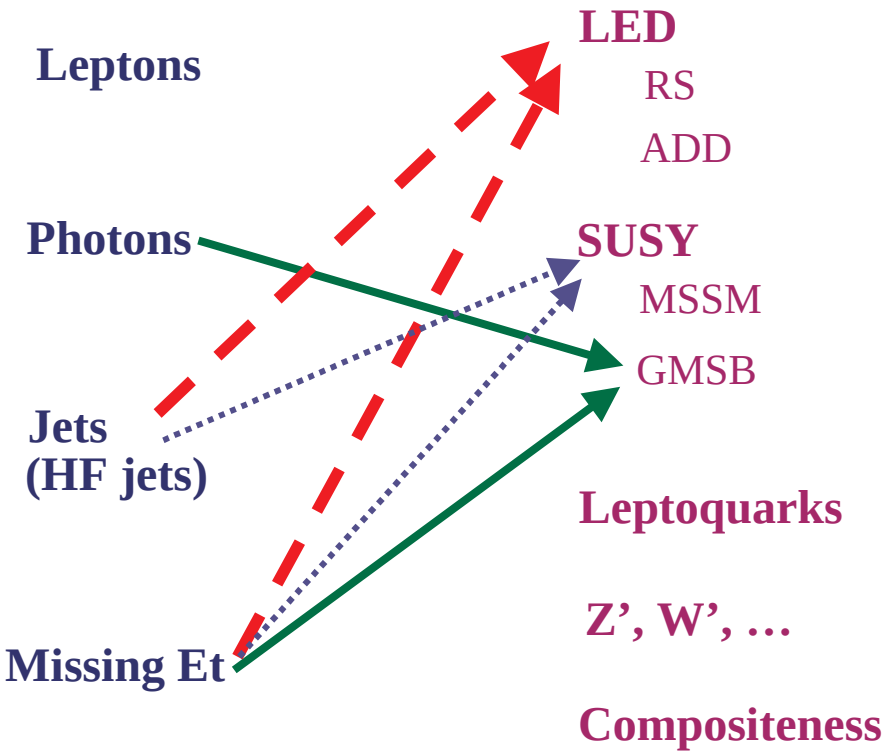
# Search for Physics Beyond Standard Model

- SM theory has been remarkably confirmed by experiments over past 30 years
- However there are hints indicate new physics beyond SM
- Signs of these new physics are predicted to be very rare (otherwise we would have seen it)
- Inputs from theorists help us to know **WHAT** to look for
- Challenge for the experimentalists : **HOW** !
  - Production rates, luminosity,…
  - Detection efficiency
  - Suppress background
  - Differentiate signal and background

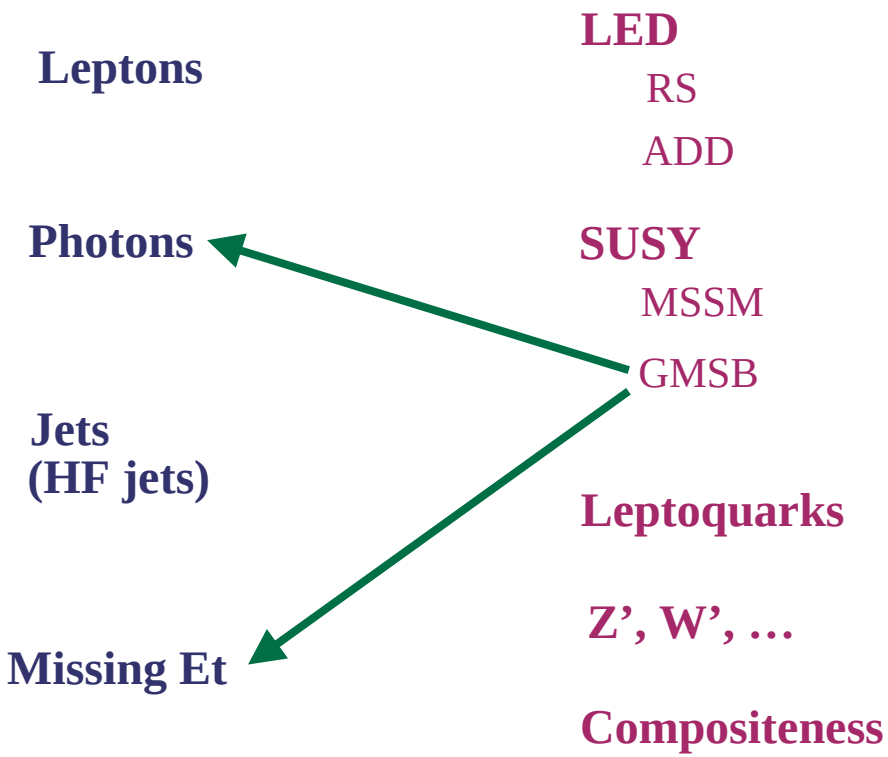


# Strategy

Signature based searches




Model based searches




- Pro : sensitive to many models
- Con : not best sensitivity for a specific signal

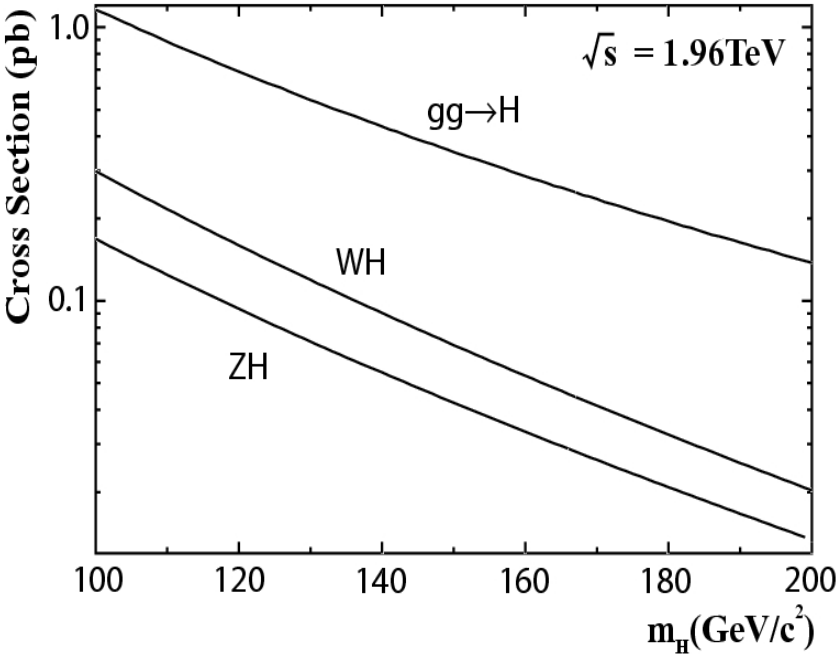
- Pro : best optimized for a specific model
- Con : model may become out-dated

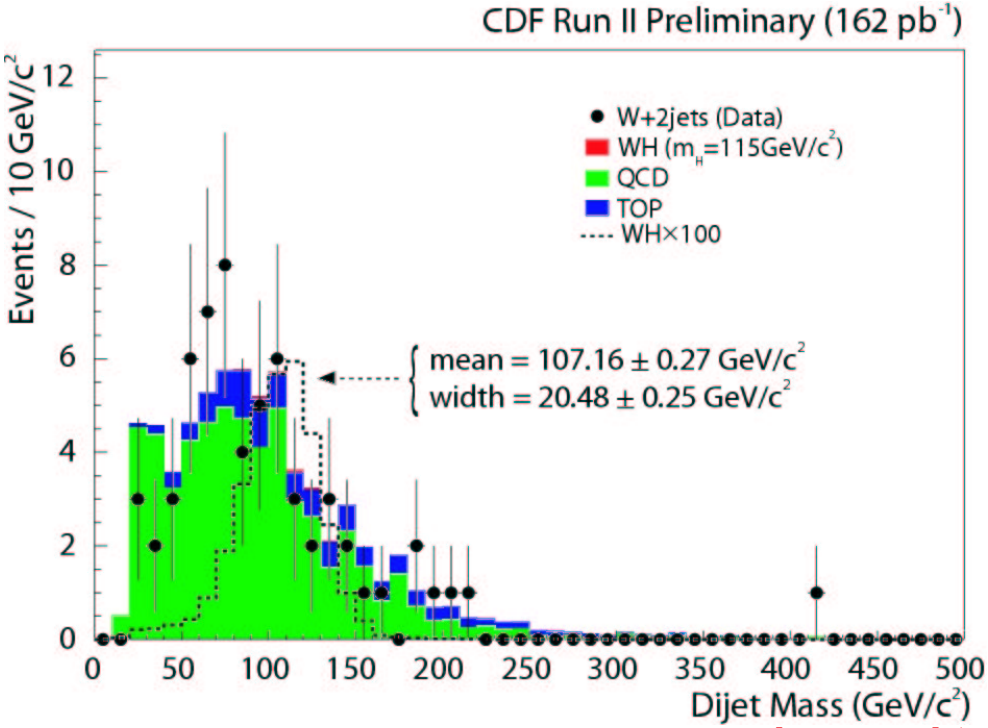
- Report results on searches with Run 2 data (L~200 $pb^{-1}$)
- Employ both search strategies

# Searches for Higgs

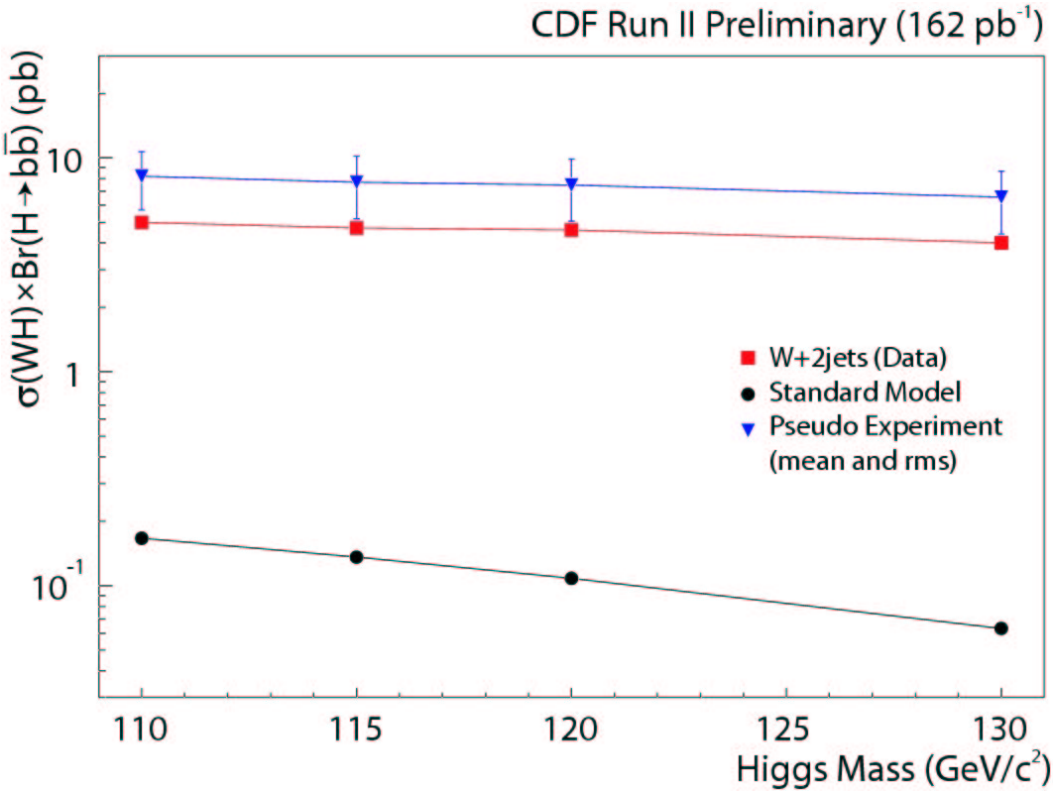
# Search for Standard Model Higgs

- CDF look for Higgs in the associated production:
  - $p\bar{p} \rightarrow WH \rightarrow l\nu b\bar{b}$
- Selection:
  - High pt lepton data (L=162 pb-1)
  - One high pt central *e* or μ, large MET (MET>20 GeV)
  - 2 jets (at least one is tagged as b-jet)
  - Veto events w/ >1 lepton (suppress ttbar)




- Backgrounds:
  - QCD
    - Mistags
    - Wbb, Wcc, Wc
    - QCD
  - TOP
    - tt, single t, di-boson, $Z(\rightarrow\tau\tau)$




- Improved limit over Run1, but sensitivity of current search is limited by statistics
- Future improvement :
  - Include forward electron
  - Improvement jet energy resolution
  - Improve b-tagging
  - Combine with other channels $(ZH \to \nu\nu b\bar{b})$

# Neutral Higgs Bosons at High Tanβ in Muti-jets Events

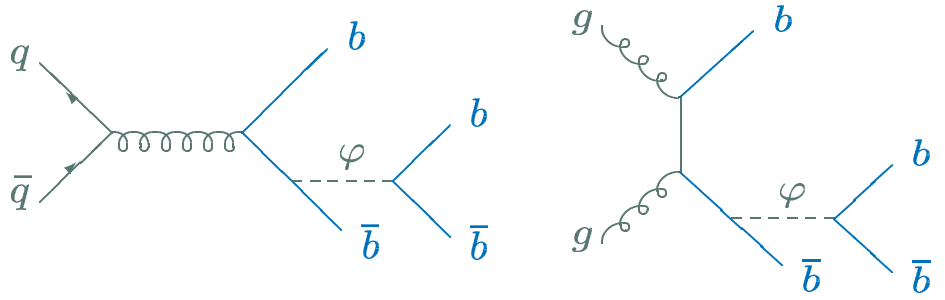
DØ search for non-SM neutral Higgs:

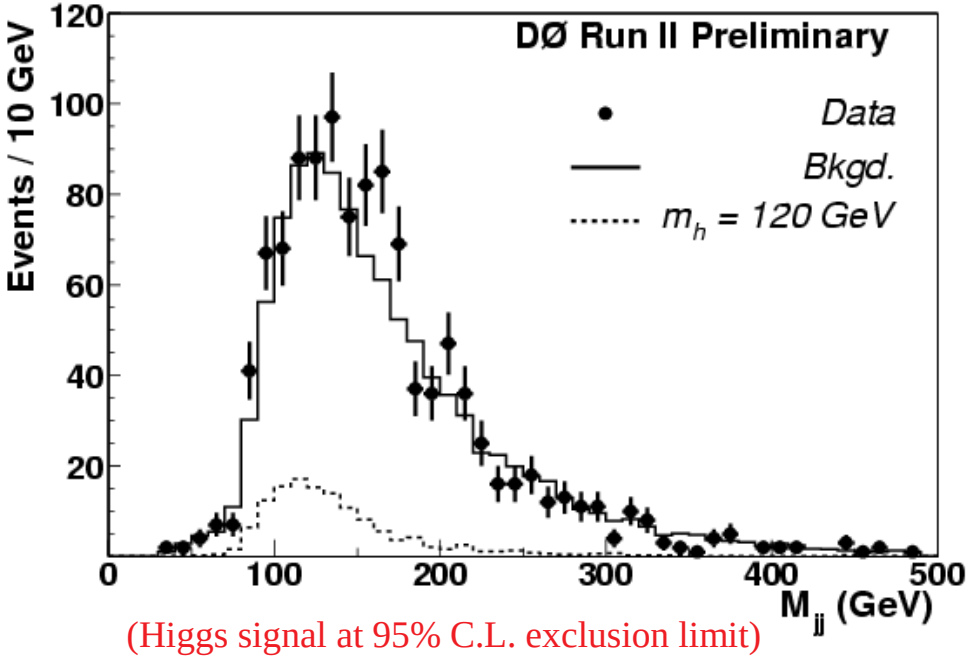
$$gg, qq \rightarrow \phi + b\bar{b} \rightarrow b\bar{b}b\bar{b} \quad (\phi = h, H, A)$$

$$\mathrm{BR}(\phi \rightarrow b\bar{b}) \sim 90\%$$

## Event Selection:

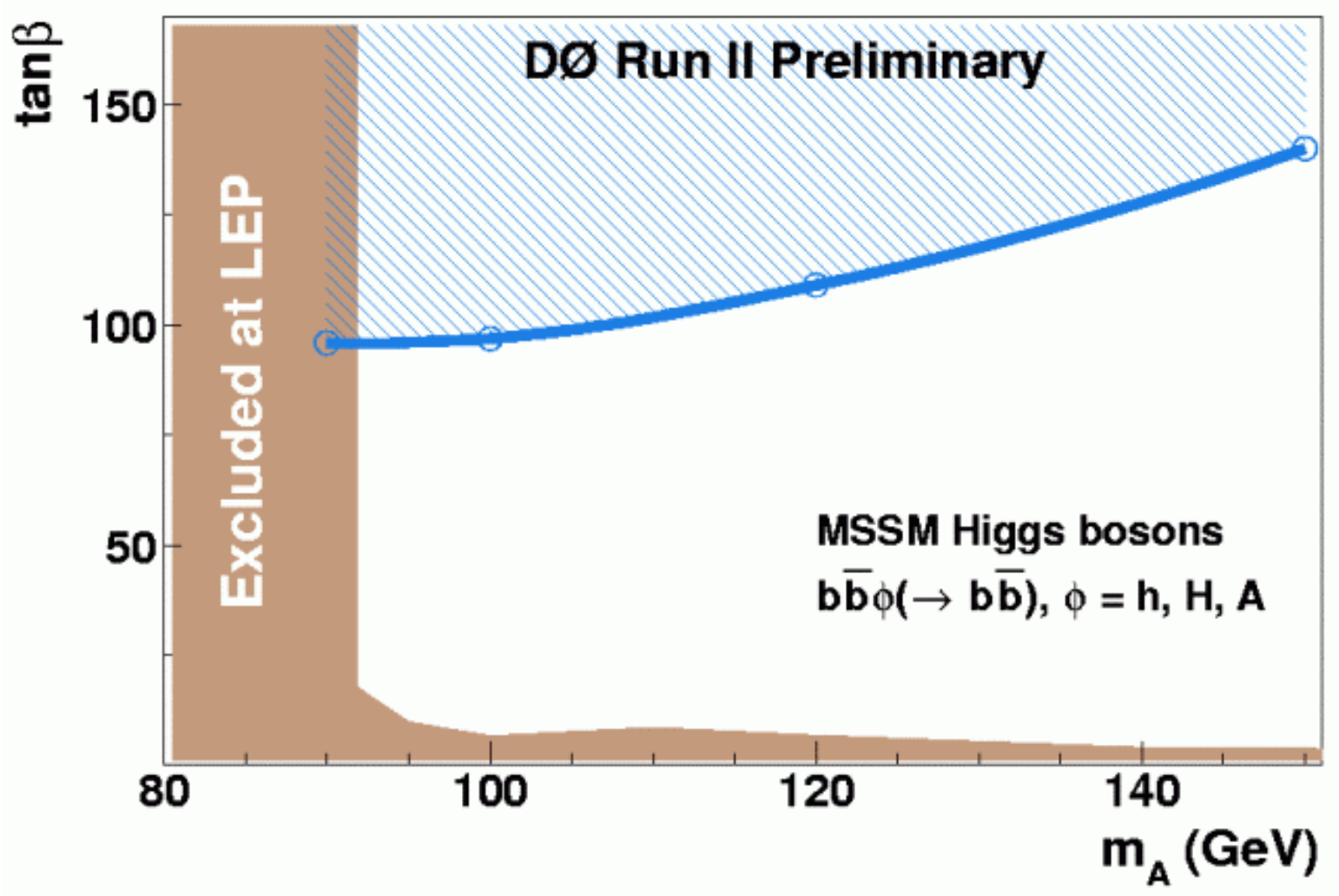
- Multi-jet data sample (L=131pb$^{-1}$)
- At least 3 jets (Et cuts on jets are optimized separately for different Higgs mass points, and for min. # jets required in the event)
- ≥ 3 b-tagged jets
- Look for signal in the invariant mass spectrum from the two leading b-tagged jets
- Backgrounds :
  - QCD multi-jets (light-jets : u,d,s,c heavy-jets : b)
  - Others (tt, Z(→bb)+jets,..)



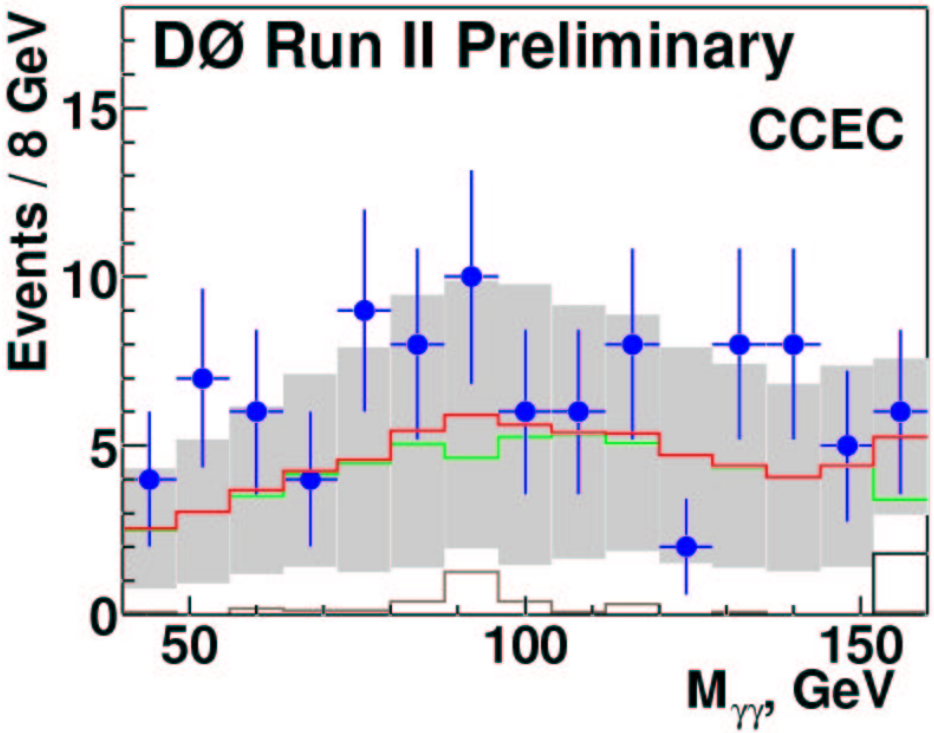

(Higgs signal at 95% C.L. exclusion limit)

# Neutral Higgs Bosons at High Tanβ in Muti-jets Events



# Search for Non-SM Light Higgs in H→γγ

- Some extensions of SM contain Higgs w/ large B(H→γγ)
  - Ferimophobic Higgs : does not couple to fermions
  - Topcolor Higgs : couple to top (only non-zero fermion coupling)
  - At low Higgs mass, B(H→γγ) dominates




- DØ used 191 $pb^{-1}$ Run2 data to search for Higgs in these two scenarios
  - 2 EM objects (pass γ-ID), Et > 25 GeV in CC (central calor) or in EC (end calor)
  - Pt(γγ) > 35 GeV

data = 97.0

bkgd = 68.8 +- 45.8

QCD = 64.0 +- 45.7

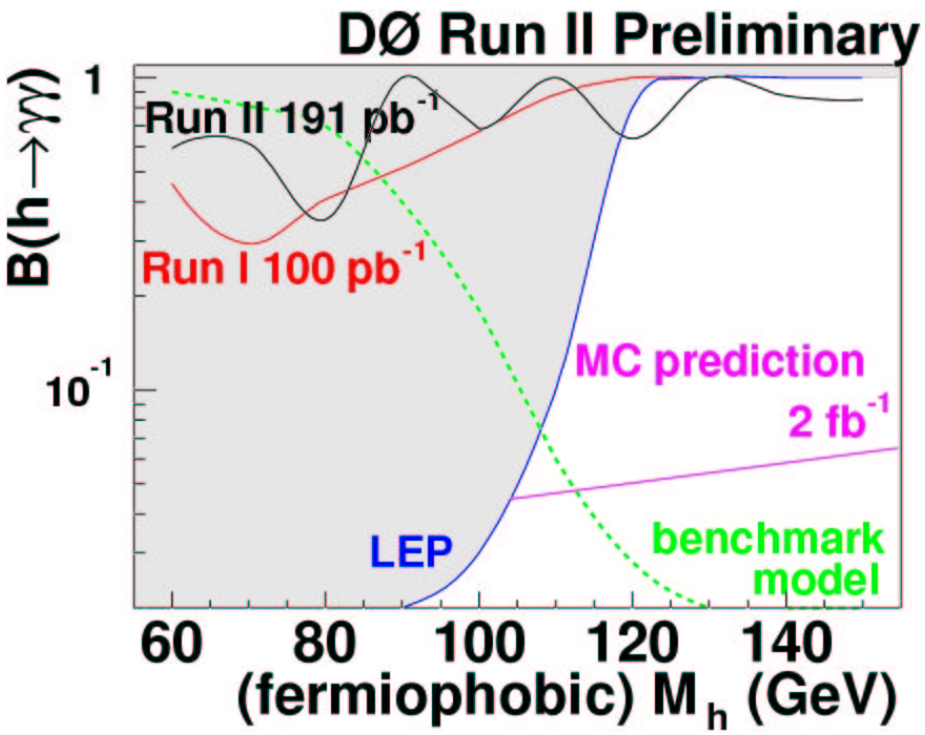
DY = 3.0 +- 3.0

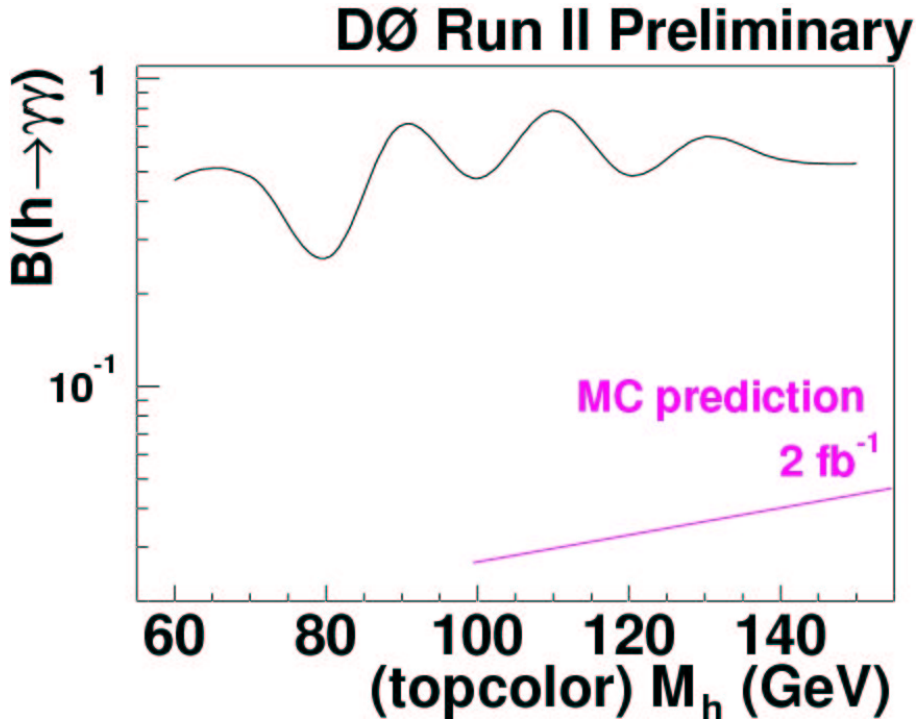
γγ = 1.8 +- 0.1

- Dominant uncertainty in background estimation is in the measurement of γ mis-ID rate (~30%)

•No clear evidence of excess

•Perform counting experiments on optimized sliding mass window to set limit on B(H→γγ) as function of M(H)



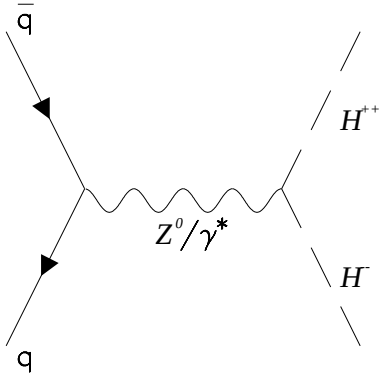



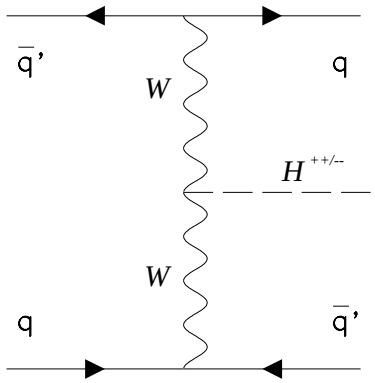
# Search for H++

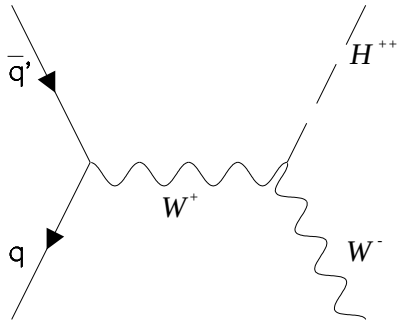
- H++/-- predicted in models that contain Higgs triplets
  - Left-Right (LR) symmetric models
  - SUSY LR models : low mass (~100 GeV – 1 TeV)

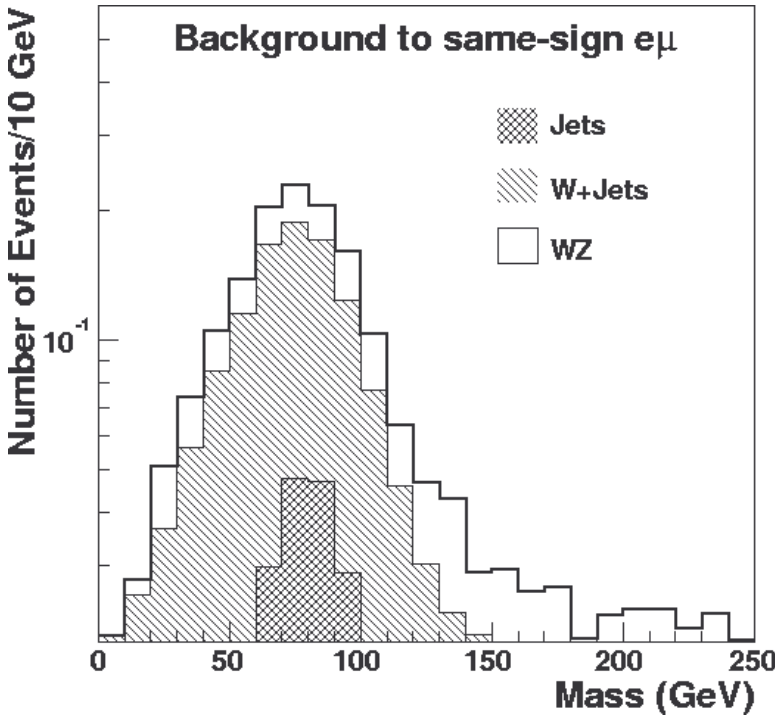
## Event Selection:

- CDF Select $H^{++/--}$ pair or singly produced
- Search for 1 pair of same sign *ee*, or μμ, or *e*μ in mass window of ±10%*M(H++) (~3σ detector resolution)
  - same sign leptons decay contains low SM backgrounds, provide clean environment for new physics search
- Datasets : inclusive high Pt electron/muon samples (~240 $pb^{-1}$ for both)

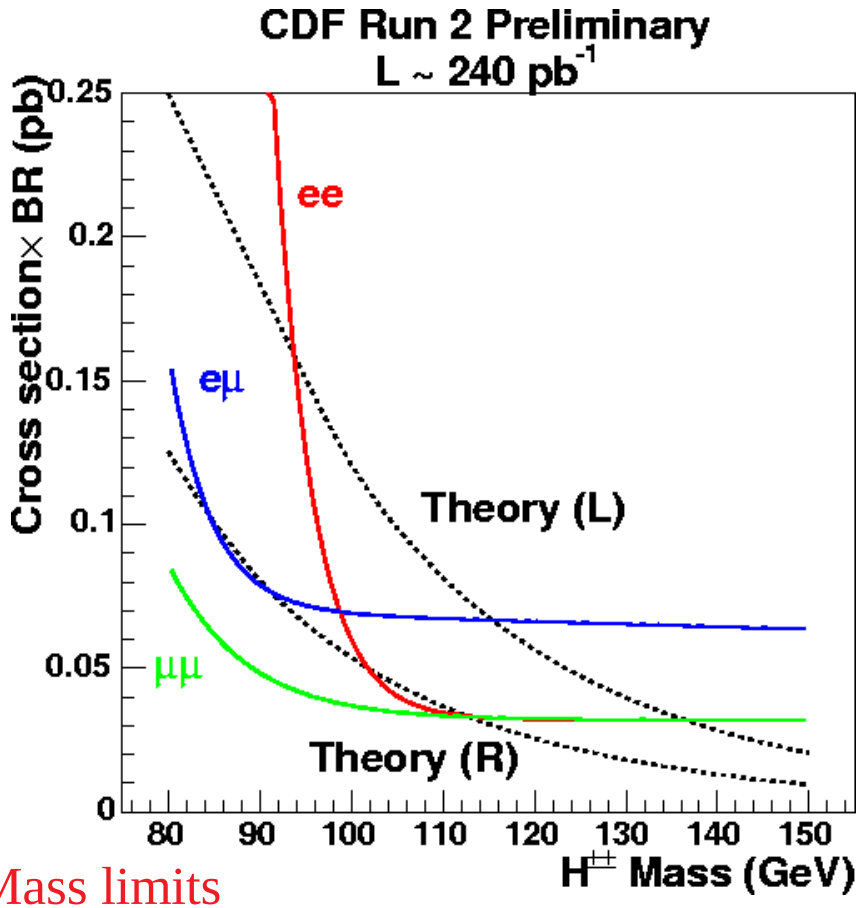





- Predicted backgrounds in same-sign *eμ* decay




- Background prediction for M(l+l+) >80 GeV (>100 GeV for *ee*)

| Decay Channels | # predicted Evts |
|---|---|
| *ee* | $1.8^{+0.8}_{-0.6}$ |
| μμ | $0.8^{+0.6}_{-0.5}$ |
| *eμ* | $0.9^{+0.4}_{-0.4}$ |

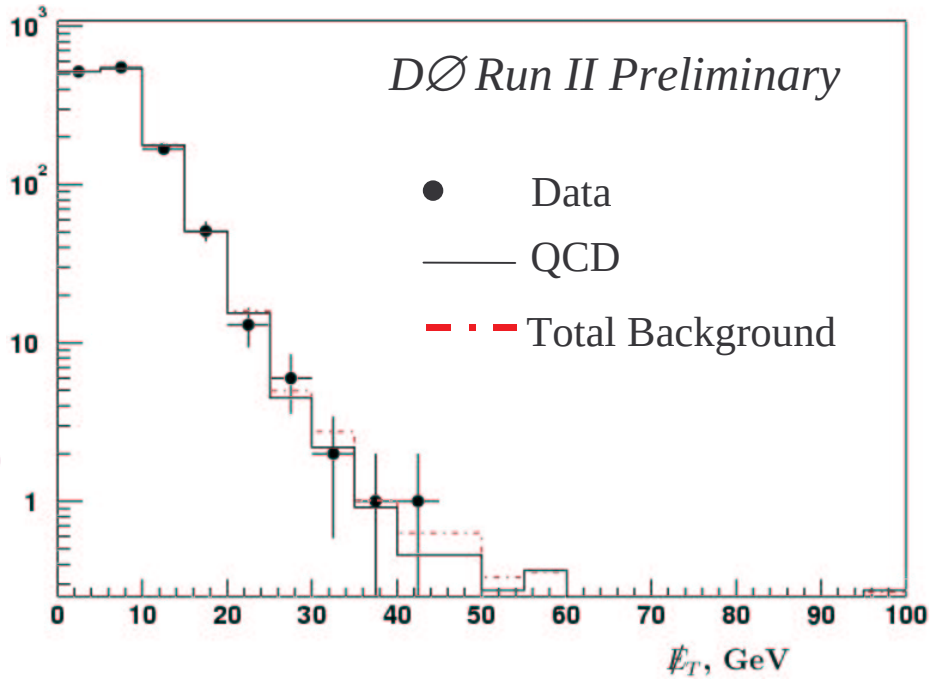
- Data : observe 0 event

Mass limits

| | CDF | | DØ | |
|---|---|---|---|---|
| | $H_L^{++}$ | $H_R^{++}$ | $H_L^{++}$ | $H_R^{++}$ |
| *ee* | 135 | ~102-113 | | |
| μμ | 135 | 113 | 116 | 95 |
| *eμ* | 115 | | | |

# Search for GMSB SUSY in γγ+MET

- In GMSB model, gravitino $\tilde{G}$ is the LSP, and NLSP is either $\tilde{\chi}_1^0$ or slepton
- In the case $\tilde{\chi}_1^0$ is the NLSP => $\tilde{\chi}_1^0 \to \tilde{G}\gamma$
- If RP is not violated => have γγ + MET in the final state
- DØ performed search with L=185 $pb^{-1}$ data
- SM contributions to γγ+MET :
  - MET due to mis-measurement :
    - QCD w/ direct γ, or jets mis-ID as γ
    - DY w/ both *e* mis-ID as γ
  - True MET :
    - $W\gamma \to e\nu\gamma$ (lost track)
    - $Wj \to e\nu j$ (lost track, jet fake as γ)
    - $Z \to \tau\tau \to ee + X$ (lost track)
    - $t\bar{t}, WW, WZ$



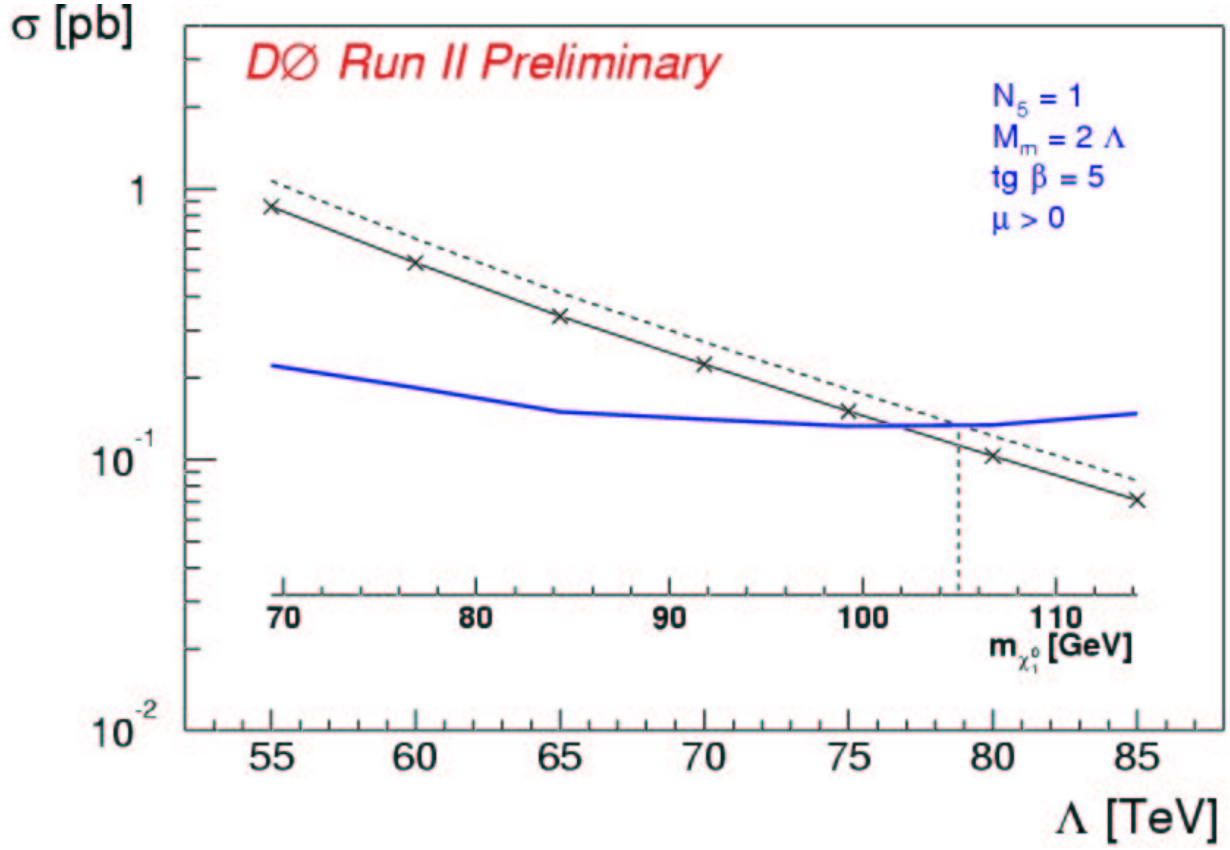
- Optimized cut value : MET > 40 GeV
- Nexpect = 2.5±0.5
- Nobs = 1
- Set 95% C.L. limit :
  - $\Lambda$ > 78.8 TeV
  - M( $\tilde{\chi}_1^0$ ) > 105 GeV
  - M( $\tilde{\chi}_1^+$ ) > 180 GeV

N5 = 1

$M_m = 2\Lambda$

tan(β) = 5

μ > 0




Most stringent limits in the class of model considered in this analysis to date !

# Searches for Leptoquarks

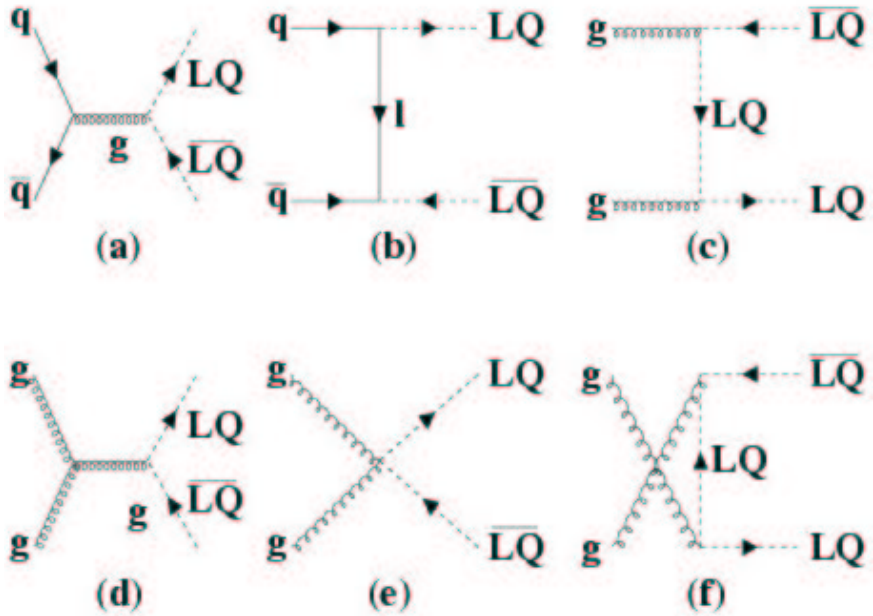
# Leptoquarks

- In SM, symmetry between leptons and quarks
  - Representation of fermion fields under SM gauge groups
  - Replication over 3 family generation
- Could indicate new symmetry between lepton and quarks => new particles
- Leptoquark
  - Appears in several extension of SM : GUTS, Technicolor, Compositeness, SUSY (RPV)
  - Scalar or vector, color triplet bosons
  - Carry L and B, fractional EM charge
  - Assume LQ couples to lepton and quark of same generation to avoid FCNC constraint => 3 generation LQ

- LQ decays :
  - $LQ \rightarrow lq$ $(l = e,\mu,\tau)$ $\beta = 1$
  - $LQ \rightarrow \nu q$ $\beta = 0$

  } β:branching ratio to charged lepton

- LQ production at Tevatron:
  - Predominantly pair produced through gluon splitting
  - $\sigma$(M=200 GeV) ~ 0.3 pb

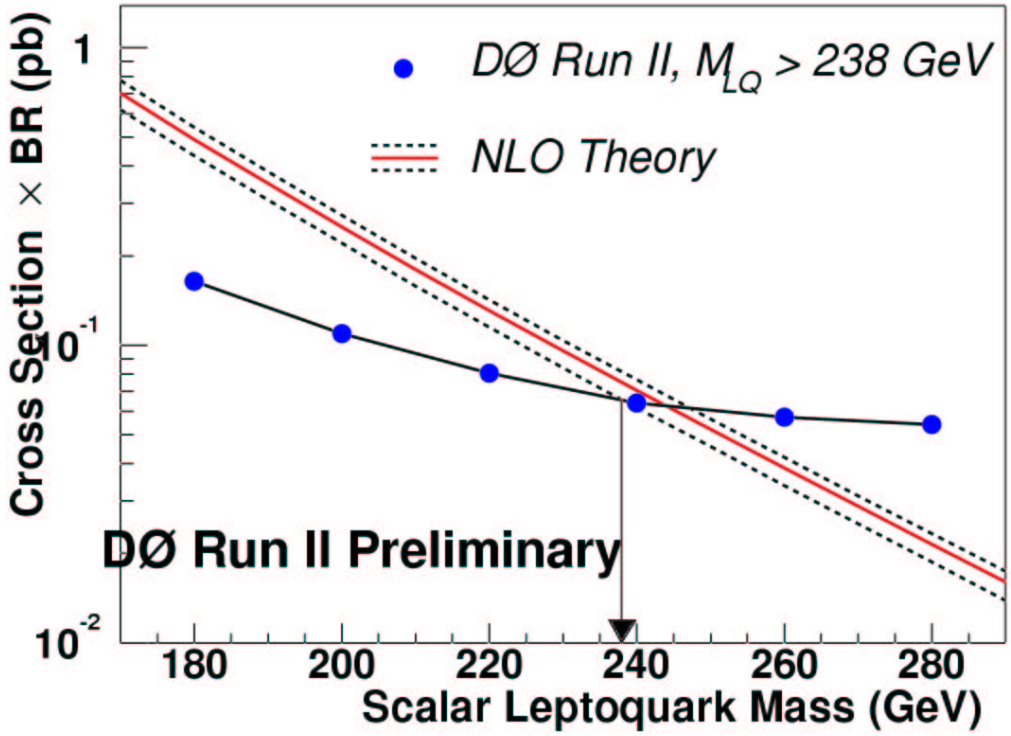


# 1st Generation Leptoquarks (Scalar)

•DØ searched for 1st gen LQ with L=175 pb$^{-1}$

- $LQLQ \rightarrow eeqq$
- $LQLQ \rightarrow e\nu qq$

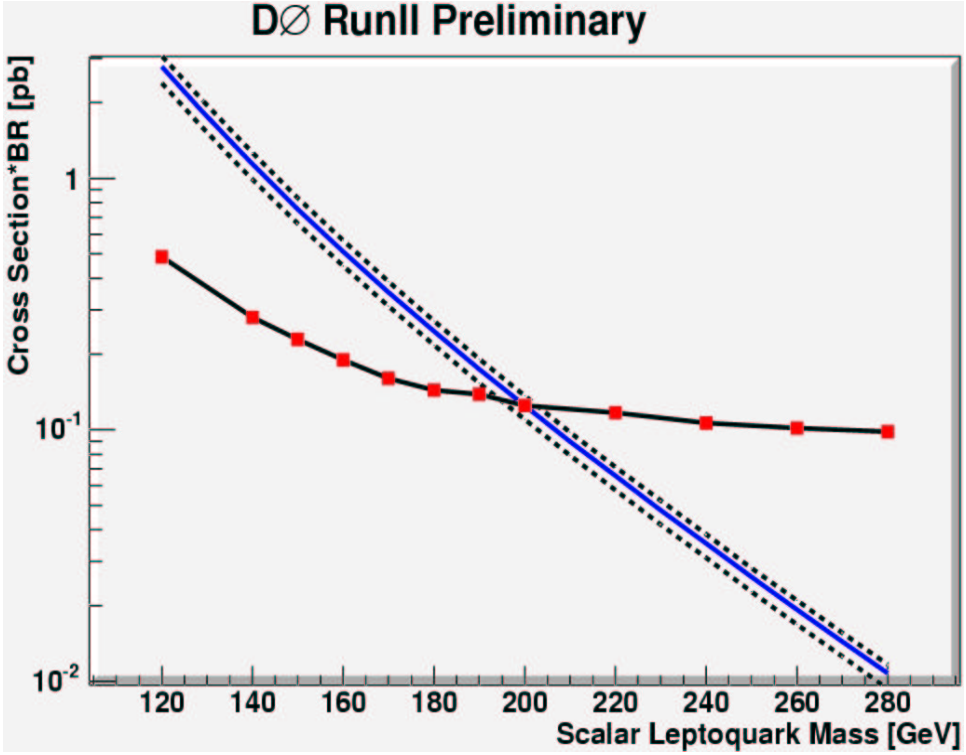
- **eejj**
  - 2 EM clusters , Et > 25 GeV (at least 1 EM cluster w/ track matched)
  - ≥ 2 jets, Et>20 GeV, |η|<2.4
  - Z veto (80<$M_{ee}$<102 GeV)
  - Scalar sum ΣEt(eejj) > 450 GeV
    - At high LQ mass, *e*,j more energetic than SM background
  - Nexpect = 0.4±0.1 (DY/Z, QCD fakes, top)
  - Nobs = 0
  - Signal acceptance ~ 10% – 30%

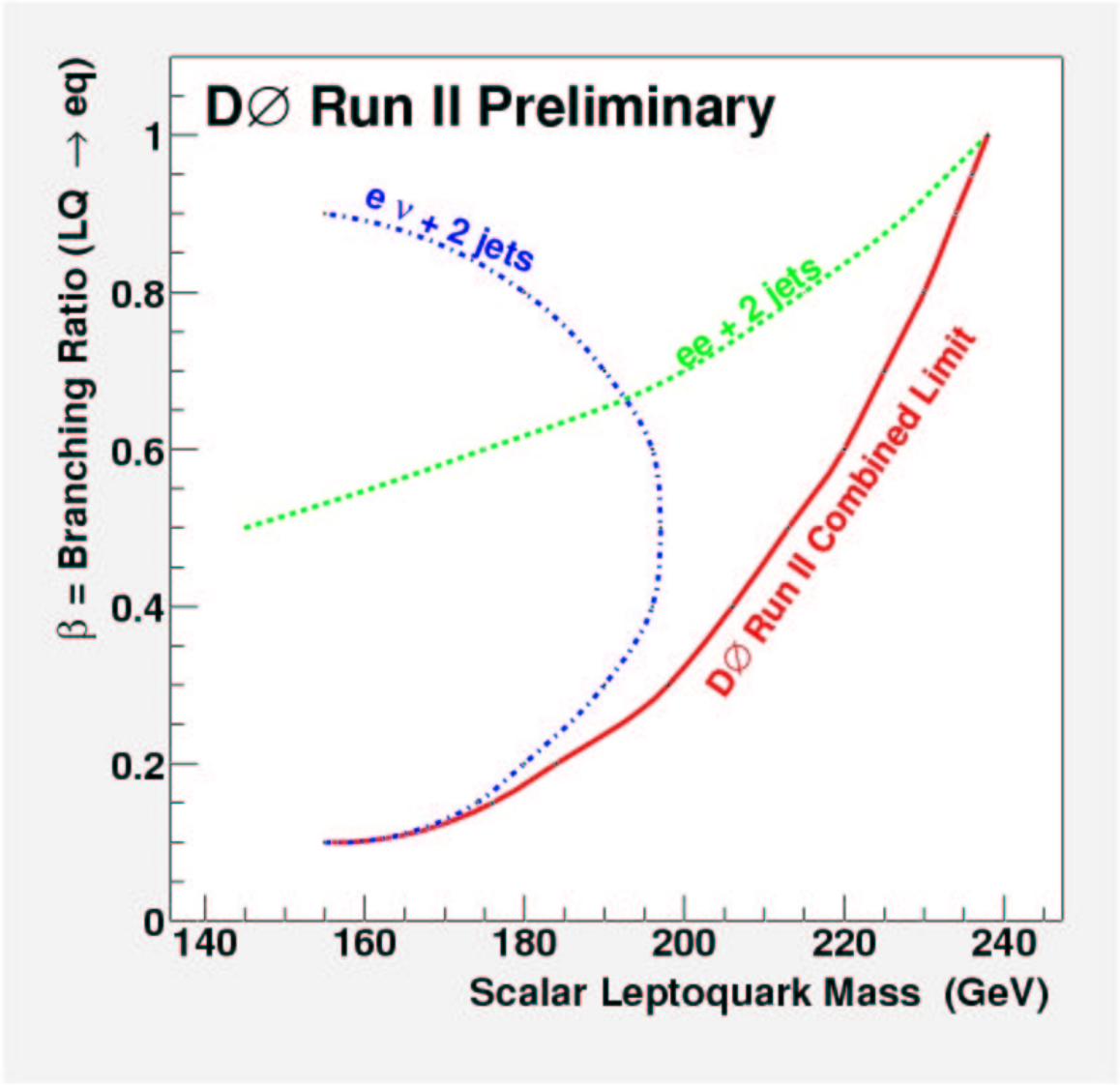



•Exclude at 95% C.L. $M_{LQ}$<238 GeV

# 1st Generation Leptoquarks (Scalar)

- **eνjj**
  - 1 EM cluster, Et>35 GeV, track match
    - EM cluster is isolated
  - 2 jets, Et>25 GeV, $|\eta|<2.5$
  - MET > 30 GeV
  - $\Delta\phi$(EM,MET) > 0.7
    - *e* and ν well separated, from different LQ
  - $M_T(e\nu)>130$ GeV (veto W+jets)
  - Scalar sum $\Sigma Et(e,MET,jj)>330$ GeV
  - Nexpect=4.7±0.9 (QCD,W,ttbar)
  - Nobs=2
  - Exclude at 95% C.L. $M_{LQ}<194$ GeV

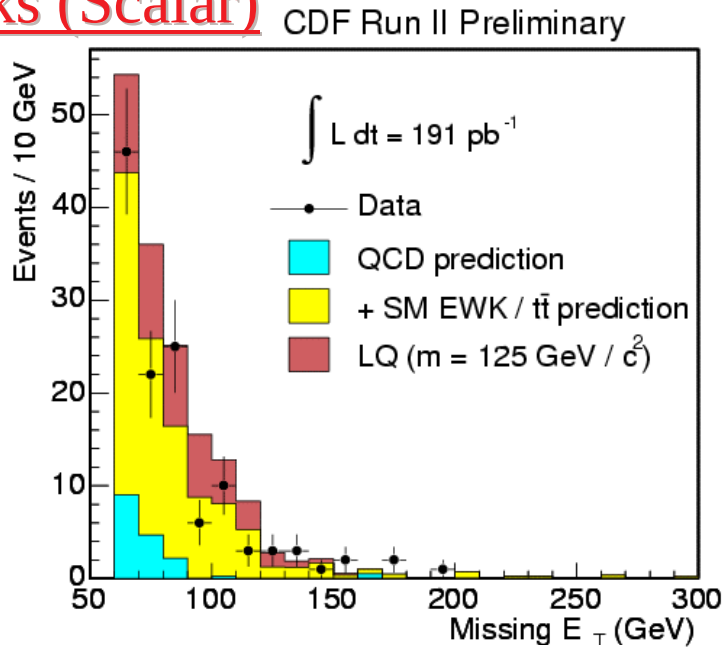


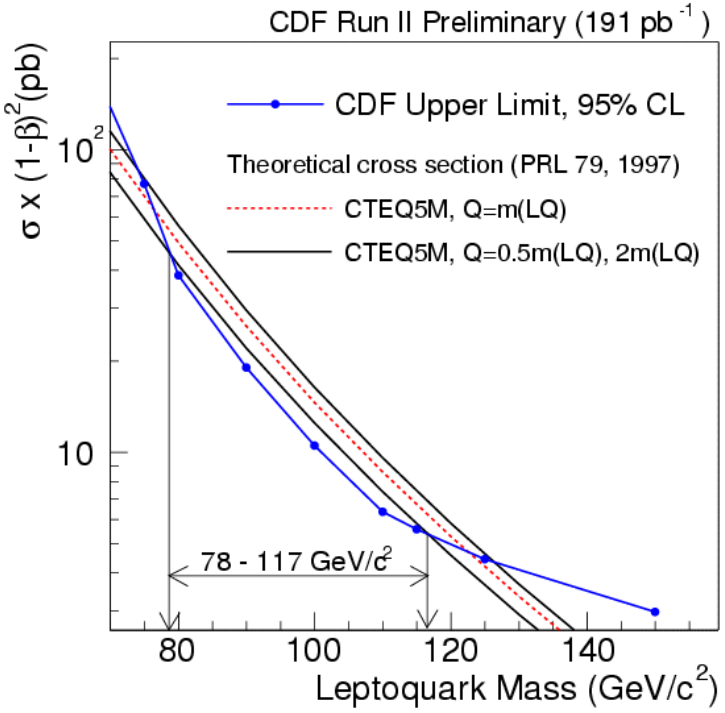



95% CL lower limit on β as function of mass of 1st gen. LQ

# 1st Generation Leptoquarks (Scalar)

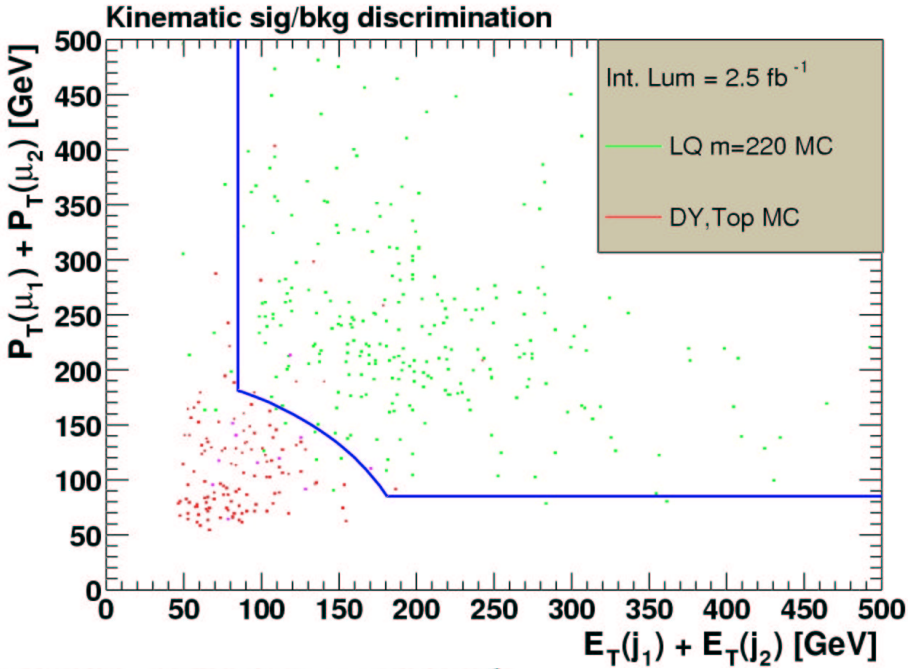
- CDF searched for $LQLQ \rightarrow \nu\nu qq$ w/ L=191pb$^{-1}$
- Selections:
  - 2,3 jets (1st,2nd leading jets in central region)
  - Large MET (MET>60 GeV)
  - Jets and MET directions not aligned (reject QCD, MET due to energy mis-measurement)
  - Veto events w/ e,μ candidates, and require central jets w/ ≥4 tracks (veto τ hadron)
- Signal acceptance ~1%-8%
- Nexpect=118±14 (W/Z+jets, QCD)
- Nobs=124
- Exclude at 95% C.L. 78<$M_{LQ}$<117 GeV

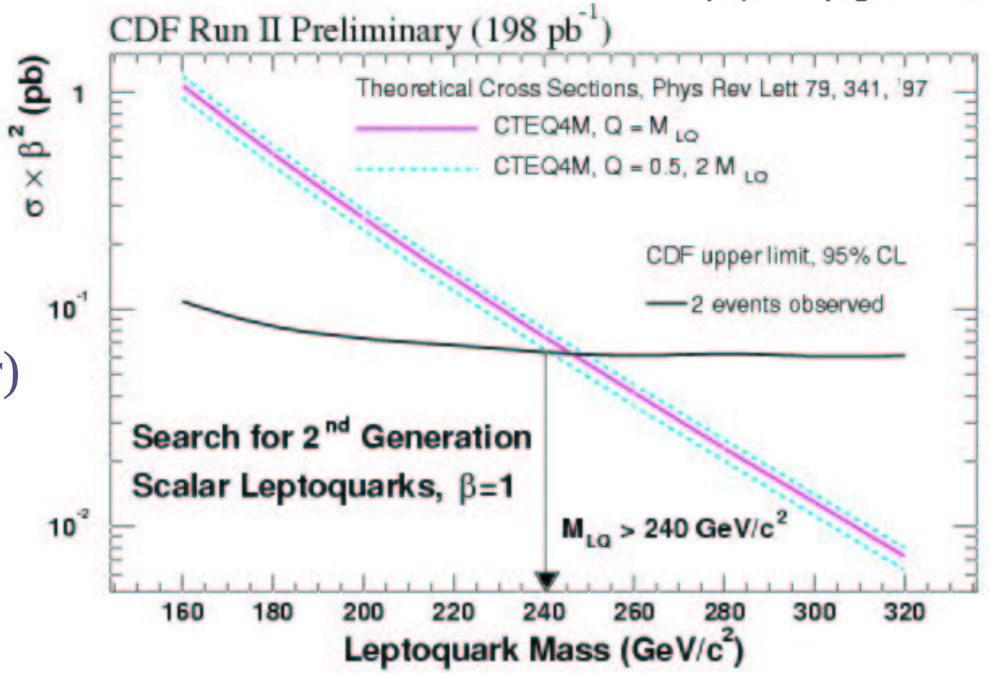


# 2nd Generation Leptoquarks (Scalar)

- $LQLQ \rightarrow \mu\mu qq$ searched by CDF using data w/ L=198 pb$^{-1}$
- Selections:
  - 2 high Pt muon candidates (Pt>25 GeV)
  - 2 jets (Et>15,30 GeV)
  - Veto events :
    - $M_{\mu\mu}$<15 GeV (J/ψ,Υ)
    - 76<$M_{\mu\mu}$<110 GeV (Z)
  - ΣEt(jet1,jet2)>85 GeV, ΣPt(μ1,μ2)>85 GeV
  - $\sqrt{(\Sigma \text{jetEt})^2+(\Sigma \mu \text{Pt})^2} > 200$ GeV
- Nexpect = 3.2±1.2 (DY+jets, QCD, ttbar)
- Nobs = 2
- Exclude at 95% C.L. $M_{LQ}$<240 GeV



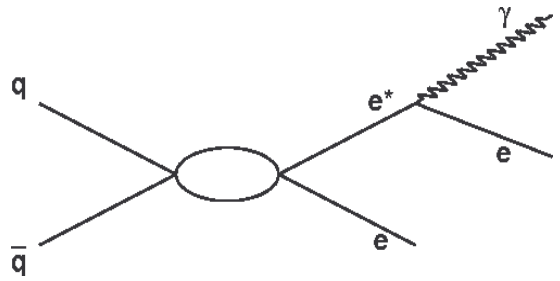
# Summary on Leptoquark Search at Tevatron Run 2

| Scalar LQ | | CDF | | DØ | |
|---|---|---|---|---|---|
| Generation | β | $M_{LQ}$ (GeV) | | $M_{LQ}$ (GeV) | |
| | | Run 1 | Run 2 | Run 1 | Run 2 |
| 1st | 1 | 213 | Update in progress | 225 | 238 |
| | 0.5 | 182 | 166 | 204 | 194 |
| | 0 | | 78-117 | 98 | |
| 2nd | 1 | 202 | 241 | 200 | 186 |
| | 0.5 | 160 | | 180 | |
| | 0 | | 78-117 | 98 | |

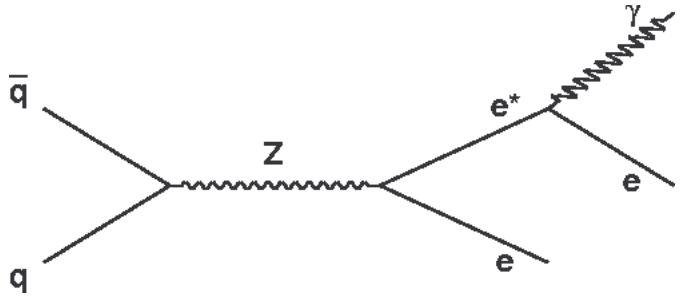
Run 1 3rd generation results are not shown here

# Search for Excited Electron

- Large number of *q* and *l* in SM may suggest they are composite particles, consist of more fundamental entities
- Observation of excited states of *q* and *l* => clear sign that *q*,*l* are not elementary particles
- CDF searched for excited electron ($e^*$)using high pt electron data (L=200 $pb^{-1}$)
- At Tevatron, $e^*$ can be produced via contact interactions or gauge mediated interactions




Contact Interaction




Gauge Mediated Interaction

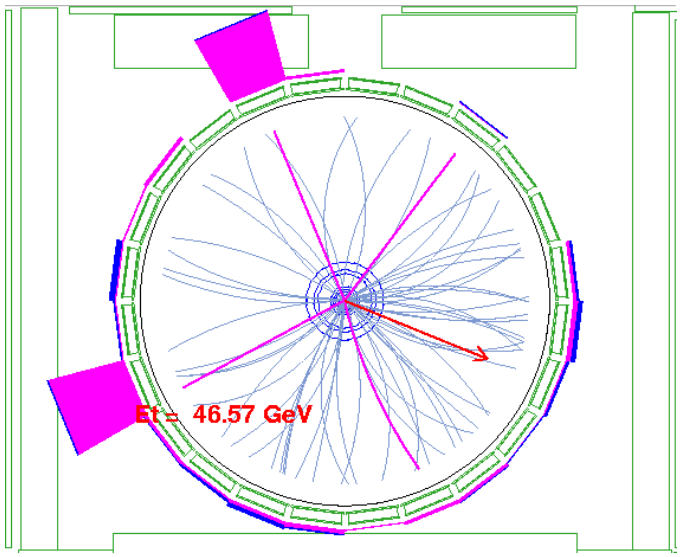
## Event Selection:

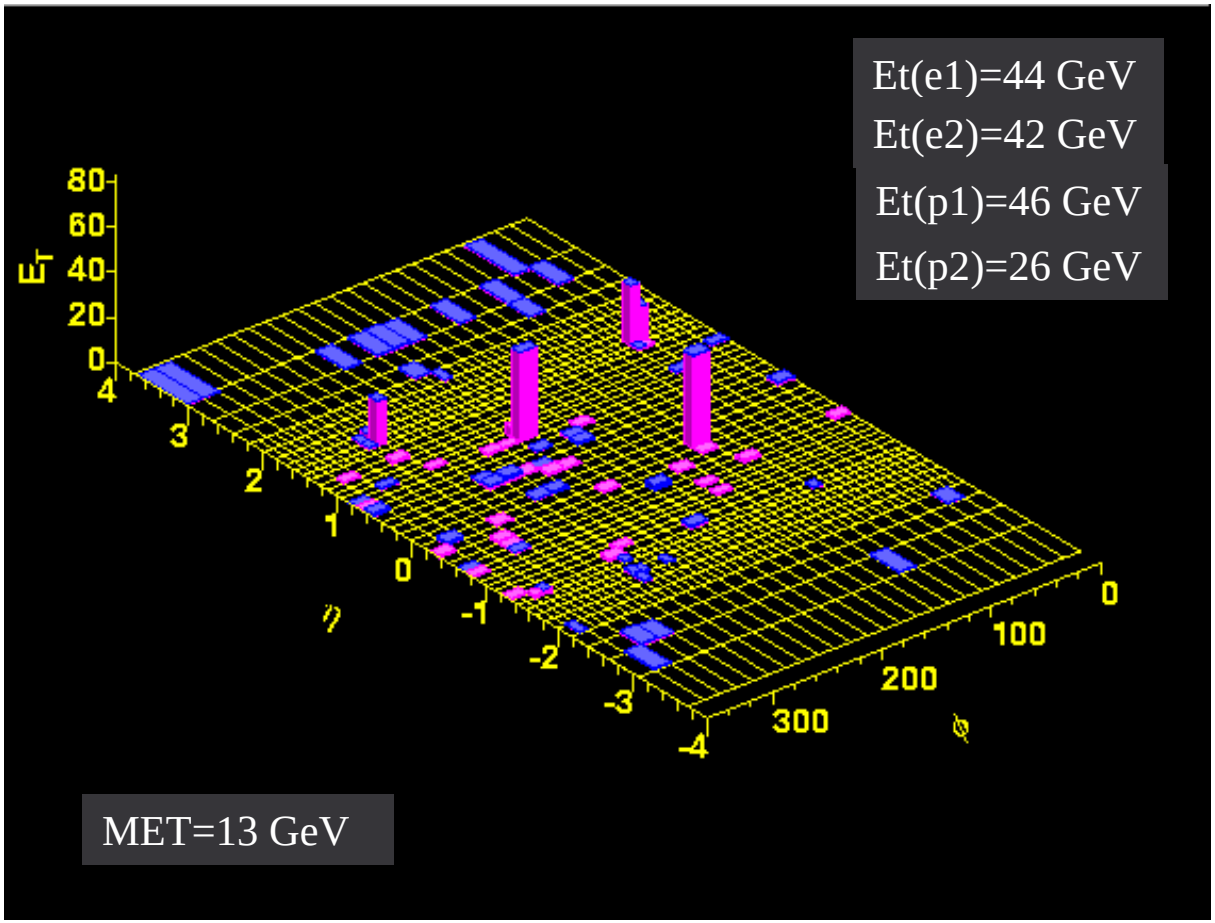
- Select events w/ *ee*γ in the final state
- Look for resonance in M(*e*γ)
- SM backgrounds :
  - Zγ + DY , Z+jets, WZ, Multi-jets, γγ+jets, …

- Expect 3 events, observe 3 events

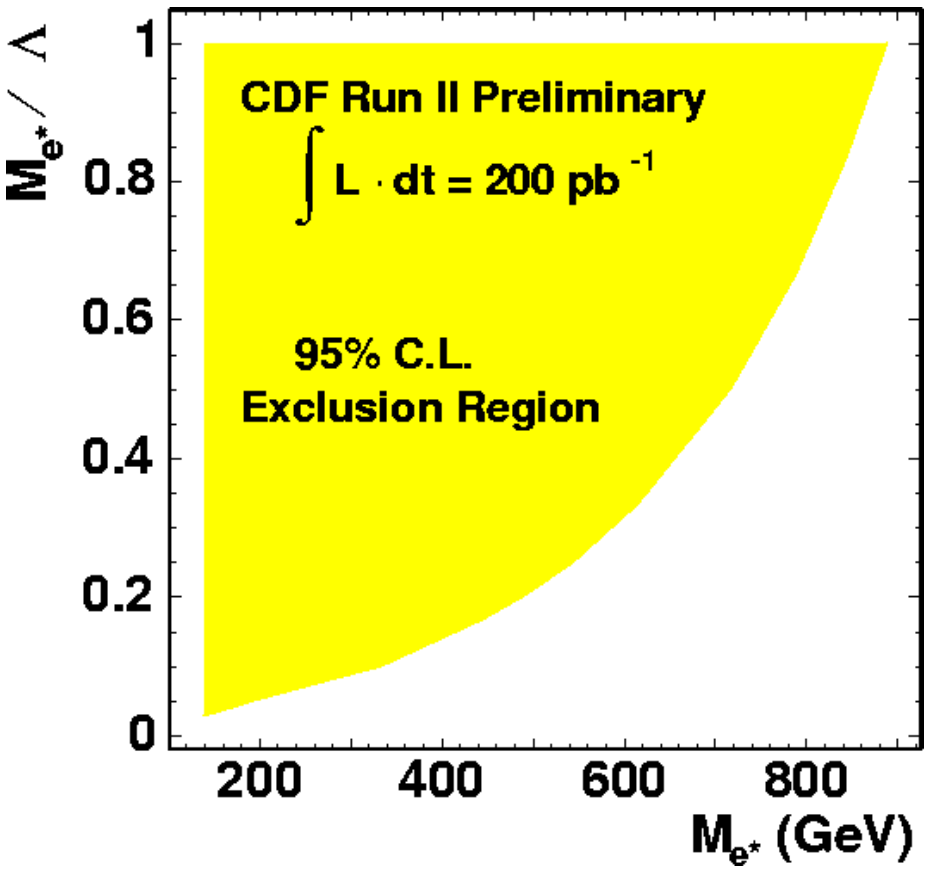
# Search for Excited Electron

- 4 EM candidates
  - Could be ZZ event!

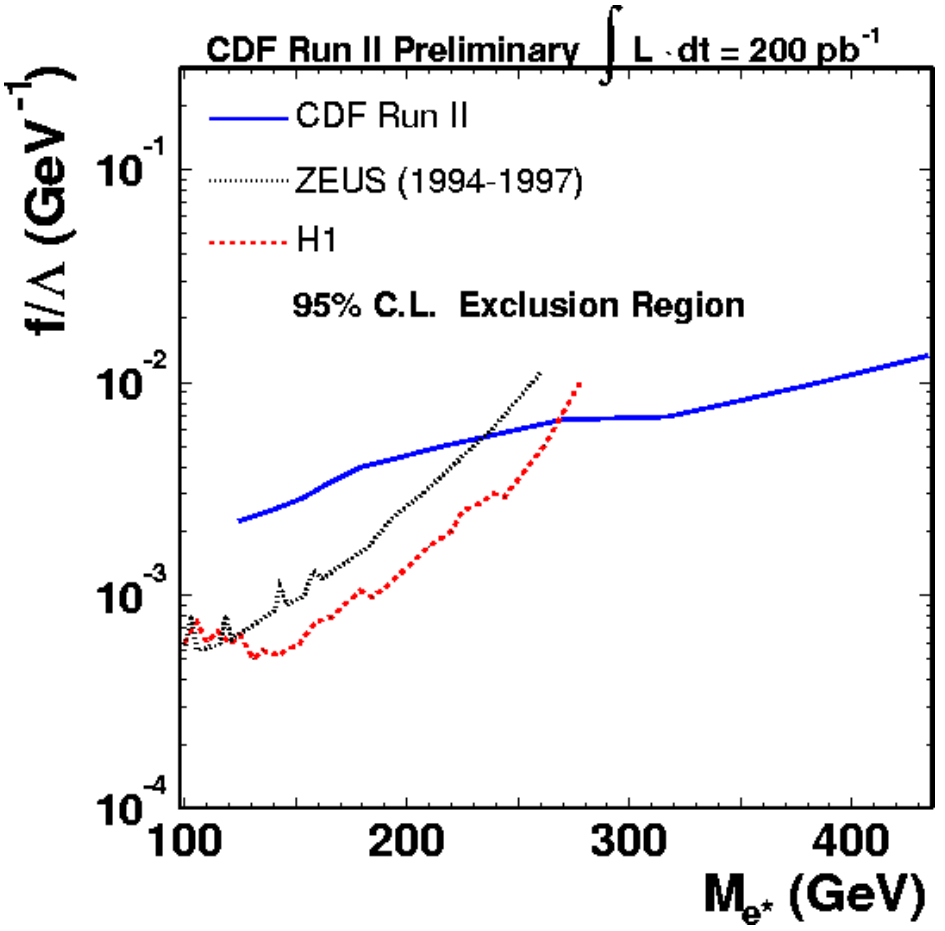


Contact Interaction Limit




Gauge Mediated Interaction Limit




- $\Lambda$ : compositeness scale
- f : relative coupling strength to $SU(2)_L$ gauge boson

# Summary

- Tevatron Run 2 is really underway
- Both experiments have analyzed up to ~200 $pb^{-1}$ (2X Run 1)
- Seen some of the new results, and they are as Competitive or Better than Run 1
- Hear more exciting results in Jim Linnemann's talk